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EXPERIMENTS ON THE INTERNAL DISPERSION OF OPTICAL WAVES

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ABSTRACT. It has been observed that the spectral lines obtained by passing monochromatic light through a plane grating, placed in different liquid media are broadened to different extents. This broadening effect is a particular characteristic of the liquid, and is determined by the discrepancy between the elastic wave absorption coefficient calculated by Stokes and the observed value. It has been considered that this discrepancy which is a measure of the range of variability of the molecular coefficients, is effective in producing a change in the optical wave velocity also.

INTRODUCTION

The real part of the dielectric constant, K, in a medium, obtained from considerations of the electronic motion, determines the optical wave velocity. We have the standard relation for the dielectric constant (Slater and Frank, 1933) in the form,

$$K = 1 + \frac{4\pi\Sigma N_K \epsilon^2/m}{f_K^2 - \omega^2 + i\omega g}$$

so that,

$$n^2 - k^2 \simeq n^2 = \frac{C^2}{V^2} = 1 + \frac{4\pi\Sigma N_K \epsilon^2/m(f_K^2 - \omega^2)}{(f_K^2 - \omega^2)^2 + \omega^2 g^2} \quad \ldots \quad (1)$$

Here, C, and V, denote the optical wave velocity in vacuum and in the medium, n, the index of refraction and k, the coefficient of absorption, ϵ and m denote the electronic charge and the mass, $\omega = 2\pi\nu$ determines the frequency of the impressed waves, g is the coefficient of frictional force and f_{K0}^2 is the coefficient of the force of restitution, where

$$f_K^2 = f_{K0}^2 - \frac{4\pi}{3} N_K \epsilon^2/m.$$

The relations give a dependence of 'n' or 'V' on ω or ν and hence a dispersion. When f_K^2 and g are of definite magnitudes, we have, that for a particular frequency, the velocity in the medium V is fixed and thus λ determined by the relation $V = \nu\lambda$, is also fixed. We obtain a measure of λ from the plane grating relation,

$$(a + b) \sin\theta = N\lambda$$

where 'N' is the order number. For a monochromatic radiation, with a definite value of ν, it should give us a geometrical line spectrum. In actual cases, however, the spectral lines have got a definite width, determined, mainly, by the Doppler broadening of the source of light.

It has, also, been shown by Dutta (1952) elsewhere in this number referred to as paper I that the molecular motion will set the dielectric constant K, modified by an additional amount in the form

$$K = 1 + \frac{4\pi\Sigma N_K \epsilon^2/m}{f_K^2 - \omega^2 + i\omega g} + \frac{4\pi\Sigma N_K p_\mu^2 \left(1 + \frac{f(\epsilon)}{3}\right).I.}{F^2 - \omega^2 + i\omega G} \quad \ldots \quad (2)$$

where, I is the moment of inertia of the molecule, F and G denote the molecular coefficient of restitution and of friction, and

$$f(\epsilon) = \frac{4\pi}{3} \frac{\Sigma N_K \epsilon^2/m}{f_K^2 - \omega^2 + i\omega g}$$

If the F and G values were fixed quantities, like the electronic f and g values, we would have obtained a slightly modified value of V and thus also of λ and θ of the diffraction spectra relation. When, however, a range of values of F and G, the molecular coefficients, are taken into account, the range of variability being determined by the Stokes multiplier M, as discussed by Dutta in paper I, we would obtain for a particular value of ν a range of values of V and also of λ. This would give us a broadening of the spectral lines obtained by a diffraction grating, provided F and G have effective values in the equation (2). Such a range of values of V associated with a particular value of ν, has been termed as 'internal dispersion' of optical waves. This will give a range of values of λ and hence a broadening of the spectral lines. According to the contention of Dutta, (paper I,) the spectral line breadth will be determined by the M values of the substance and will be different in the case of different liquids. The general character of the observed diffraction spectral lines show the effectiveness of the molecular forces of friction and restitution and the results are in complete accord with the point of view that the associated breadth of the spectral lines are determined by the values of M, the Stokes multiplier. This has been described in the following experiment.

EXPERIMENTAL

A plane ruled grating, with 250 lines per cm. was immersed in different liquids and the diffraction spectra were photographed at a constant room temperature. The spectroscope used was a Hilger constant deviation one, remodelled as a straight type spectroscope. The source of light was a powerful sodium lamp used with a bichromate filter. A critical study of the diffraction spectra relation makes it clear that the actual position of the grating in the liquid medium is immaterial in determining the width of the spectral lines. They will be determined by the molecular structure of the liquid and by the length of

the liquid column traversed by the light. In the present experiment, different liquids were tried in a vessel, with a light path of about 3 inches. The results recorded here, were obtained by placing the grating more or less centrally in the medium and in such a way that the spectra on the two sides of the central line were equally deviated.

It was observed, however, that the intensities of the spectral lines for different liquids were very different from each other. Indeed, in some of the liquids like benzene and xylene, the diffraction spectra lines with the plane grating could not be obtained at all. It may be pointed out, however, that one obtains the diffraction spectral lines of these liquids with a wave-field grating without any difficulty. This is perhaps due to the smaller angle of diffraction in the case of the wave field grating and also to the volume of grating effect. That the absorption was not in any way the determining factor of the width of the line was clear from the fact that carbon bi-sulphide liquid, with a Stokes multiplier of 1540 (Pinkerton,1949) and carbon tetarchloride, with a Stokes multiplier of 27, both appear to have a stronger absorption than actone with $M=10$. This was judged from the intensities of the spectra obtained with the same time of exposure, when the light was allowed to pass through these different liquids. The less intense CS_2 spectral lines, however, record, with the same time of exposure, a larger width than the spectral lines through acetone, whereas, the less intense CCl_4 lines have a smaller width in comparison with acetone lines. This, presumably, is due to the fact that CS_2 has a very large value of the Stokes multiplier M and the associated spreading of the spectral lines is comparatively so large that even with weaker intensity, the lines appeared to be wider than the acetone lines, whereas, CCl_4 whose M value is not so markedly different from the M value for acetone, will have a comparatively smaller broadening effect and with a less intense line the broadening effect does not show up. In order to get a proper estimate of the broadening, however, the breadth of the spectral lines with equivalent intensities should be compared. It has been consistently observed that with equal intensities, the breadth of the spectral lines is greater in the case of liquids with a comparatively larger value of the Stokes multiplier M. A more systematic investigation of the subject would have been possible with gratings of different dispersive powers. It is, however, essentially necessary that for such a comparative study, the different gratings should have been drawn with the same ruling point. For such a systematic investigation, we have, accordingly, planned to have the necessary gratings and the work will be taken up in greater detail when the gratings will be available.

RESULTS

It has been considered, consistently with the experimental results, and also in accordance with the theoretical expectation outlined by Dutta in paper I, that the breadth of the lines with equal intensities are determined

solely by the value of the Stokes multiplier M. On this contention we take up the breadth of the spectral lines of a liquid, with the Stokes multiplier as unity, as the standard liquid whose breadth is determined solely by the Doppler broadening of the source. On a measurement of the width of the spectral lines corresponding to other liquids as medium, we can easily determine the increase in width as compared to the standared. This helps us, immediately to obtain the percentage of internal dispersion, which determines for a particular frequency, the variation of the wave velocity or of the wavelength λ, about a mean velocity. In the case of the standard substance, it is implied that for a particular frequency the wave velocity or the wavelength has a unique value only. The method of calculating the percentage of 'internal dispersion' from a measurement of the increase in width of the spectral lines, compared to the spectral lines of the standard liquid, is very similar to the method of calculating the 'internal dispersion' of elastic waves and would be treated in detail in the paper on the subject, by Dutta and Mukherjee, referred to as paper II (in course of publication). The following table gives the results of measurements on internal dispersion of optical waves in the cases of some liquids. The values of the Stokes multiplier M, as also the logarithm of the Stokes multiplier have been tabulated for comparison. It will be observed from the table that there is a consistent increase of the internal dispersion with the increasing value of the Stokes multiplier. The magnitude of the internal dispersion is, however, less than the magnitude of the internal dispersion of the elastic waves for any particular liquid. This is evident on a comparitive study of the results of paper II (in course of publication). It may, however, be noted that there is a close correspondence between the magnitudes of the internal dispersion and the logarithm of the Stokes multiplier, as in the case of the elastic waves also.

TABLE I

Liquid	Stokes multiplier 'M'	Logarithm of M (base 10)	Internal dispersion per thousand.
Castor oil	1	0	0
Water	3.1	0.47	0 8
Acetone	10.3	1.01	2.3
Carbon tetrachloride	27	1.43	4.0
Carbon bisulphide	1540	3.19	8.0

We remain content in showing in the above table, an effective broadening of the spectral lines obtained by passing light through a plane grating, placed

in a liquid medium. This broadening is completely unrelated to the absorption characteristics of the liquid and appears to be solely determined by the Stokes multiplier M. This is in accordance with the idea propounded by Dutta in paper I that the optical wave velocity will be affected by molecular motion in the liquid, and a broadening will be expected in accordance with the range of variation of the coefficients. A more detailed work will be undertaken.

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REVIEWS

(1)

High Frequency Measurements—By August Hund. (International Series in Pure and Applied Physics), x + 676 pages, 417 figures, McGraw-Hill Book Co. Inc., 1951, Price $ 10.

The volume under review is the second edition of the well known book on high frequency measurement by the author first published in 1933. Since the publication of the first edition, many new high frequency techniques have come into use. For example, we had no commercial FM in 1929 (when the first edition was prepared). But now FM and also PM are in wide use. The range of the frequencies to be measured has also extended enormously. The new edition, therefore, required a large amount of revision and several chapters had to be completely re-written.

The volume under reference deals with measurement procedures at low and medium radio frequencies and also at high, very high and ultra high frequencies. It is divided into seventeen chapters of which the first three are introductory dealing with fundamental relations, circuit properties and laboratory apparatus and system for h.f. measurements. The next eight chapters are devoted to the procedures for measuring voltage, frequency, capacitance, self-inductance, mutual inductance and coupling, effective resistance, h.f. power and losses and resonance. This is followed by three chapters on ferromagnetic measurements, tube measurements, modulation measurements and measurements on lines and aerial systems. Chapter XVI deals with wave propagation determinations and the last chapter describes some miscellaneous measurements, *e.g.*, noise, electrical properties of piezo-electric crystals, gain determinations of microwave antennas and UHF admittance bridge. MKS units have been used throughout the book.

One or two criticisms may perhaps be made of this otherwise excellent and useful publication. It would have been better if SHF measurements were treated in a separate chapter instead of being distributed in several places as has been done. The modern UHF and microwave measurement procedures have been given only in broad outline. Further, the author's style of presentation is sometimes rather heavy. These are, however, only minor blemishes. The book, as a whole, is exhaustive and authoritative in its treatment. As such it should find a place on the table of every radio engineer and radio physicist. The printing, binding and get-up are of the McGraw-Hill standard.

(G. S. S.)

(2)

Understanding Radio—By Watson, Welch and Eby, Second Edition, 716 pages, 522 figures, Mc-Graw-Hill Book Company, Inc., 1951, Price, $ 5.50.

This is an elementary book written for " students who have little or no background in electricity or science." As is expected in such a book, the mathematics has been kept to a working minimum and the book is made as practical as possible. The book is divided into twentysix chapters, each followed by a number of illustrative questions and list of technical terms used in the chapter. Some of the chapters headings are as follows: Radio Waves and Wave Travel (Chap. II), Ohm's Law by Simple Mathematics and Meters (Chap. V), Wave-form pictures (Chap. VIII), Dynamic Loud Speaker (Chap. XIII), Antennas (Chap. XXIII), The Very High Frequencies (Chap. XXIV), Frequency Modulation (Chap. XXV). The method adopted in preparing the text of each chapter is learn-by-doing. The book is profusely illustrated emphasising the visual-teaching approach. Towards the end, in the Appendix, a large number of data compiled from tube manuals, are given. These will be of great help to practical workers.

The book is eminently suited to those who want to learn the elements of practical radio and also to understand broadly why-it-works. Teachers in such elementary classes will find the book very useful. Undergraduate students in the colleges may also read the book with profit. We very heartily recommend the book to the large category of readers who are interested in radio as vocation or avocation, but are prevented from joining higher technical courses in the subject due to lack of systematic training in physics and mathematics.

(J. S. C.)